- APROVIS3D -

Analog PROcessing of bioinspired VIsion Sensors for 3D reconstruction

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1. Introduction

This document defines the scenarios, use cases and requirements of the demonstration that we will build in the APROVI3D project.

2. Documentation

2.1. Applicable and Referenced Documents

#	Id	Description	Identifier (Ed Rev)	Date
AD1	FPP	Full Project Proposal	1.0	15.01.2019

2.2. Glossary and Terminology

Acronym	Definition
WP	Work Package
UAV	Unmanned Autonomous Vehicles

3. Contents

Inspired from biology, the project addresses the scientific question of developing a low-power, end-to-end analog sensing and processing architecture of 3D visual scenes, running on analog devices, without a central clock and aims to validate them in real-life situations. More specifically, the project will develop new paradigms for biologically inspired vision, from sensing to processing, in order to help machines such as Unmanned Autonomous Vehicles (UAV), autonomous vehicles, or robots gain high-level understanding from visual scenes.

The main scenario for autonomous coastal monitoring relies on an analog vision system integrated on-board the UAV, that will enable autonomous navigation and data collection based on real-time coastline detection and real-time 3D reconstruction of the visual scene. The proposed scheme will be the first real-time visual servoing system implemented in an analog fashion and directly integrated with the UAVs actuation system.

3.1. Use Case 1: Autonomous Coastline Monitoring

High-level description and objective

The purpose of Use Case 1 is to demonstrate the successful integration of the technologies developed within the APROVIS3D project in an autonomous coastline monitoring scenario using a UAV. More specifically, the coastline will be detected using the signal from the bio-inspired DVS sensor, which will be processed on-line from a SNN vision algorithm running on a neuromorphic hardware (SpiNNaker). The outcome of the SNN algorithm, will be a segmented image (ground, sea, coastline), which will be incorporated on a visual servo control scheme running on a conventional CPU on-board the UAV and controlling its motion. The goal is the vehicle to autonomously follow the coastline, while retaining the latter always inside the camera field of view and as close as possible to the image center.

Scenario

The UAV will take off from its base, and in either manual or automatic mode (GPS-aided autopilot), it will be guided on top of the shore/sea separation line. At this point, the autonomous vision-based navigation and control framework will be initialized and the UAV will start to move along the coastline performing the monitoring task, while retaining the coastline always inside the camera field of view (Fig. 1). When the monitoring task is completed the UAV will return to the starting point to land.

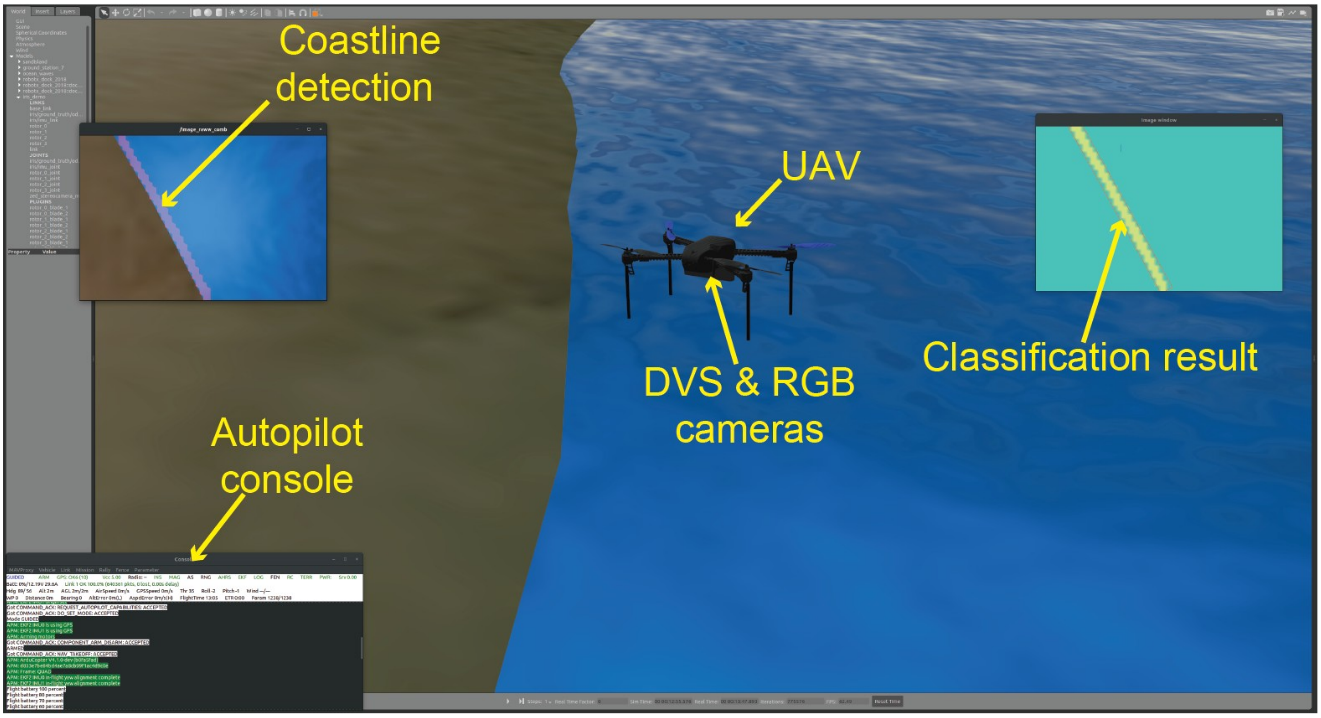

Figure 1: Use Case 1 Scenario – Autonomous Coastline Monitoring.

For the aforementioned Scenario the following hardware will be employed: i) an Octorotor UAV equipped with the necessary navigation sensor suite (GPS, IMU, altimeter, etc), ii) a DVS camera for coastline detection and optical flow estimation, iii) a neuromorphic hardware processing unit (SpiNNaker), iv) an RGB-D camera for data collection and fail-safe purposes, v) a powerful conventional embedded computing unit (Nvidia Xavier).

The detection of the coastline will be realized by processing the signal from the DVS camera using a SNN vision algorithm. The SpiNNaker neuromorphic hardware will be responsible for the DVS signal acquisition and the running of the SNN vision algorithm. The outcome of the SNN will be a segmented image with the detected coastline and an estimation of the scene's optical flow. The segmented image as well as the optical flow estimation, will be transferred on-line from the SpiNNaker to the embedded CPU of the UAV, where a visual servo control algorithm will calculate the appropriate motion commands in the form of body-velocities for the guidance of the vehicle. A low-level controller will then translate the velocity references to motor commands.

Case study

We aim to perform field experiments in coastlines of various lengths and morphologies. For example, and as an initial proof of concept, we consider to perform tests in small pocket beaches in Attica, Greece that may provide great seasonal changes and also are easily accessible for repeatable experiments (see Fig. 2). Coastlines with different morphological characteristics, shapes and lengths, will also be tested, as soon as the overall integrated system reaches into a mature state.

Figure 2: A small pocket beach close to the Hellenic Center for Marine Research (HCMR). The picture on the left was taken in 2016, while on the right in 2020, both from Google Earth.

Technical Requirements and Partners Role

In order to realize the scenario of Use Case 1 the following technological and scientifical modules are required:

DVS Camera (IMSE)

This camera will be used in order to acquire in real-time event signals that will be further used for the coastline detection and optical flow estimation. The benefits of using a DVS sensor in this scenario are the ability to handle very challenging lightning conditions and to use the difference of optical flow between the land and the sea (owing to the waves) to track the coastline.

Octorotor UAV (NTUA)

This aerial vehicle will be employed for Use Case 1 and will carry all the necessary navigation sensors (GPS, IMU, altimeter), payload sensors (DVS, RGB-D) and processing units (SpiNNaker, Xavier Nvidia) appropriately integrated to accommodate the envisioned scenario. The Octorotor is shown in Fig. 3.

Figure 3: Octorotor Aerial Vehicle

Spike Neural Network algorithm (UCA, INT & UL)

This vision algorithm, based on Spike Neural Networks (SNN) will accept as input the asynchronous events from the DVS and will provide the coastline detection in the form of a segmented image and an optical flow estimation. An example of a segmented image processed from RGB data is shown in Fig. 4. We aim to achieve a similar result by processing DVS data. It is possible, that the SNN algorithm will also exploit and fuse standard RGB image data along with the DVS data in case the environmental conditions are too challenging and the DVS data solely are insufficient to provide robust detection results. The SNN algorithm will run on a dedicated neuromorphic hardware, namely SpiNNaker.

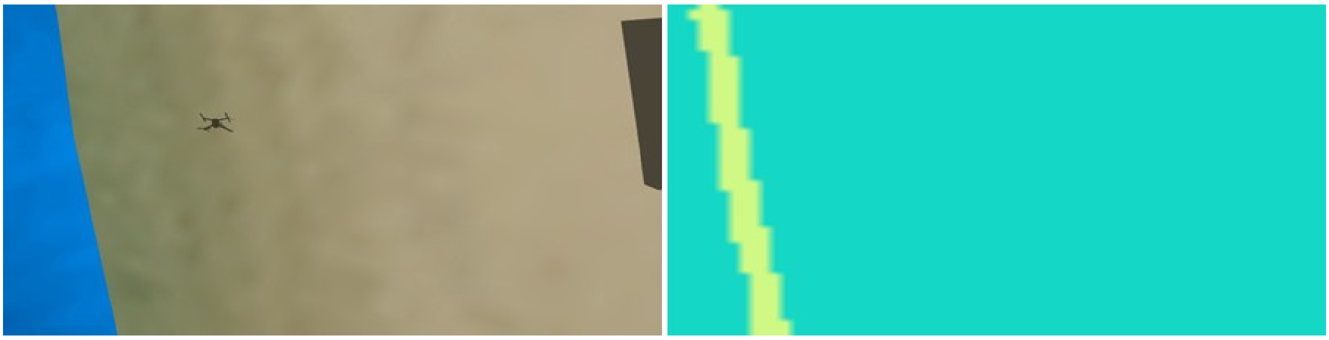

Figure 4: Left: Raw image (RGB camera). Right: Segmented image with the detected coastline

Visual Servo Control Scheme (NTUA)

This scheme will be responsible for the autonomous guidance of the UAV based on the visual information provided from the DVS camera and the SNN algorithm. More specifically, the segmented image will be fed as input to the visual controller, along with the estimated optical flow. Then, an event-based model predictive control scheme will be responsible for guiding the UAV along the coastline while guaranteeing that the latter is always retained inside the DVS camera field of view. The optical flow estimation, will be fused with the rest of the vehicle's navigation sensors (altimeter, GPS, IMU) in order to provide more accurate altitude and body velocity estimations and thus improving the overall navigation and control of the UAV. The event -triggered model predictive control scheme is considered the most appropriate choice of control for this case study, since it is able to handle efficiently the inherited non-linearities of the system, while simultaneously satisfying field of view constraints in an asynchronous fashion. The visual servoing controller will run on a traditional CPU mounted on-board the UAV (Xavier Nvidia). The event data (detected image and optical flow) will be transmitted from the neuromorphic hardware to the CPU via USB or similar communication protocol. Finally, a classic visual servo controller will also be developed, using synchronous data from a typical RGB-D sensor, just for safety reasons (i.e it will immediately engage if the DVS – based controller fails, in order to avoid possible crashes during the tuning phase) and data collection.

Neuromorphic Hardware (ETHZ)

At the moment, the partners have converged to use SpiNNaker (Fig. 5) as the neuromorphic hardware. It will be responsible for receiving the DVS signal and running the SNN algorithm. A wired communication will be established between the SpiNNaker and the Xavier Nvidia CPU, for the transmission of the data (detected image and optical flow) needed from the visual servoing control scheme.

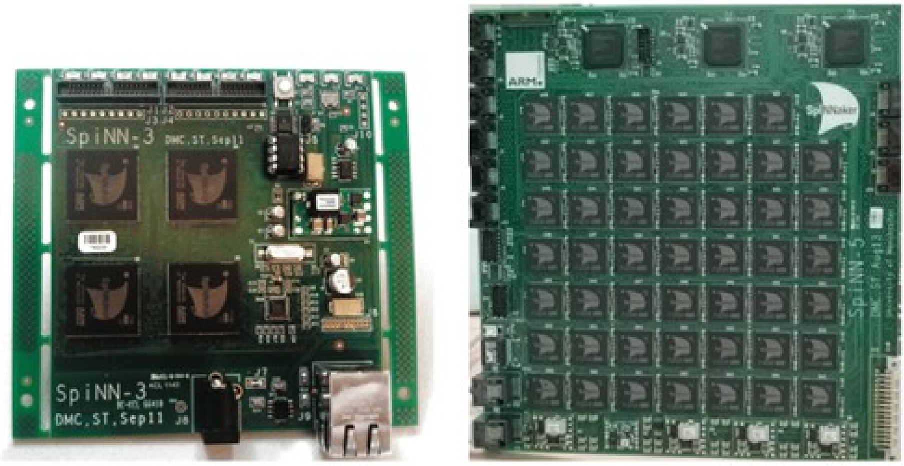

Figure 5: Examples of SpiNNAker boards

Functional requirements

One of the objectives will be to maintain the coastline as near as possible to a vertical line dividing the field of view in two equal parts. An other one will be to maintain a constant altitude by keeping the visual flow of the land part as constant as possible. In function of the technical characteristics of the UAV and of the sensors and of each flight plan, we will define the expected values of the visual flow and the control signals to send to the on-board flight controller.

Interest of foveation: to decrease the number of pixels to decrease the computation amount. Decreasing the rate of false positives by focusing on areas of interest. Advantage for motion control by controling the foveation point (additional capability) to focus on the coastline. The control of this additional degree of liberty will be studied in a second phase.

3.2. Use Case 2: stereo depth perception for 3D reconstruction of the coastline

High-level description and objective

In this use case, we target the depth perception from a pair of event sensors.

Scenario

During a UAV flight over coastal areas, a pair of event-based sensors placed in a stereo configuration will acquire depth maps of the shore. This scenario can be implemented in combination with Use Case 1, or in other scenarios such as ecological and wildlife monitoring (forest areas monitoring, animal tracking, bird counting, etc.)

In a preliminary setting, a pair of event sensors placed in a stereo configuration will acquire depth maps prior to being mounted onboard the UAV.

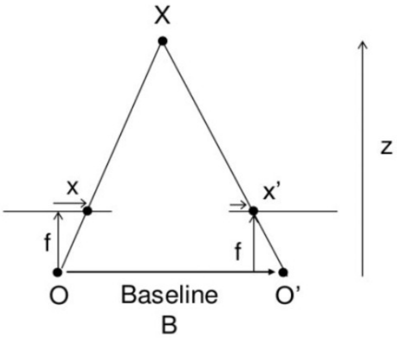

Figure 6: Stereo vision geometry.